Ignition Improvements of Lean Natural Gas Mixtures

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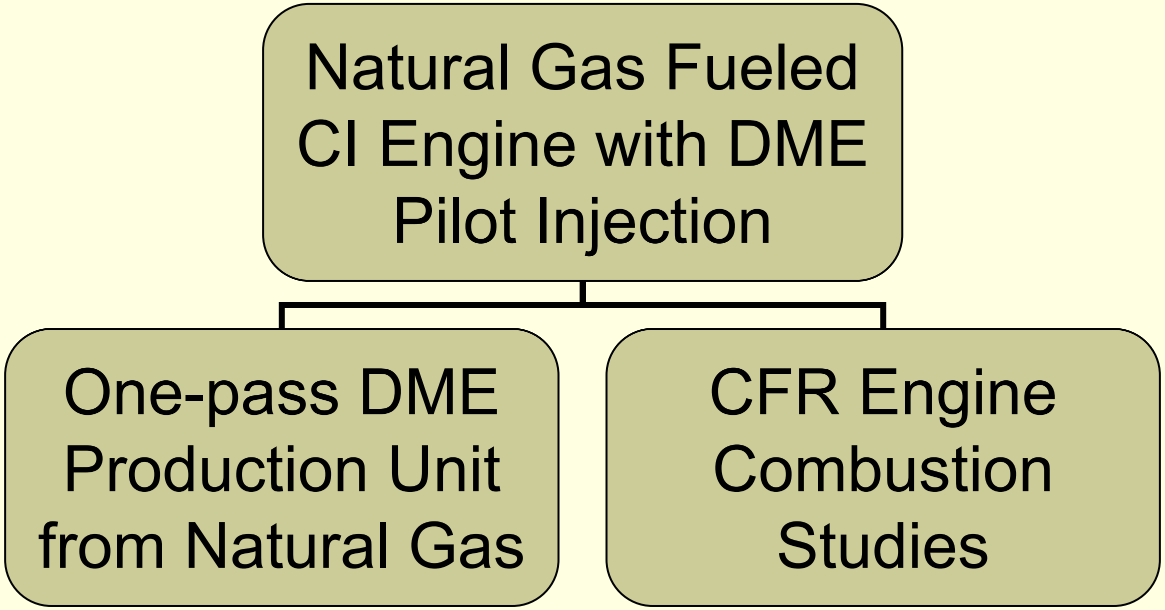
Project Overview



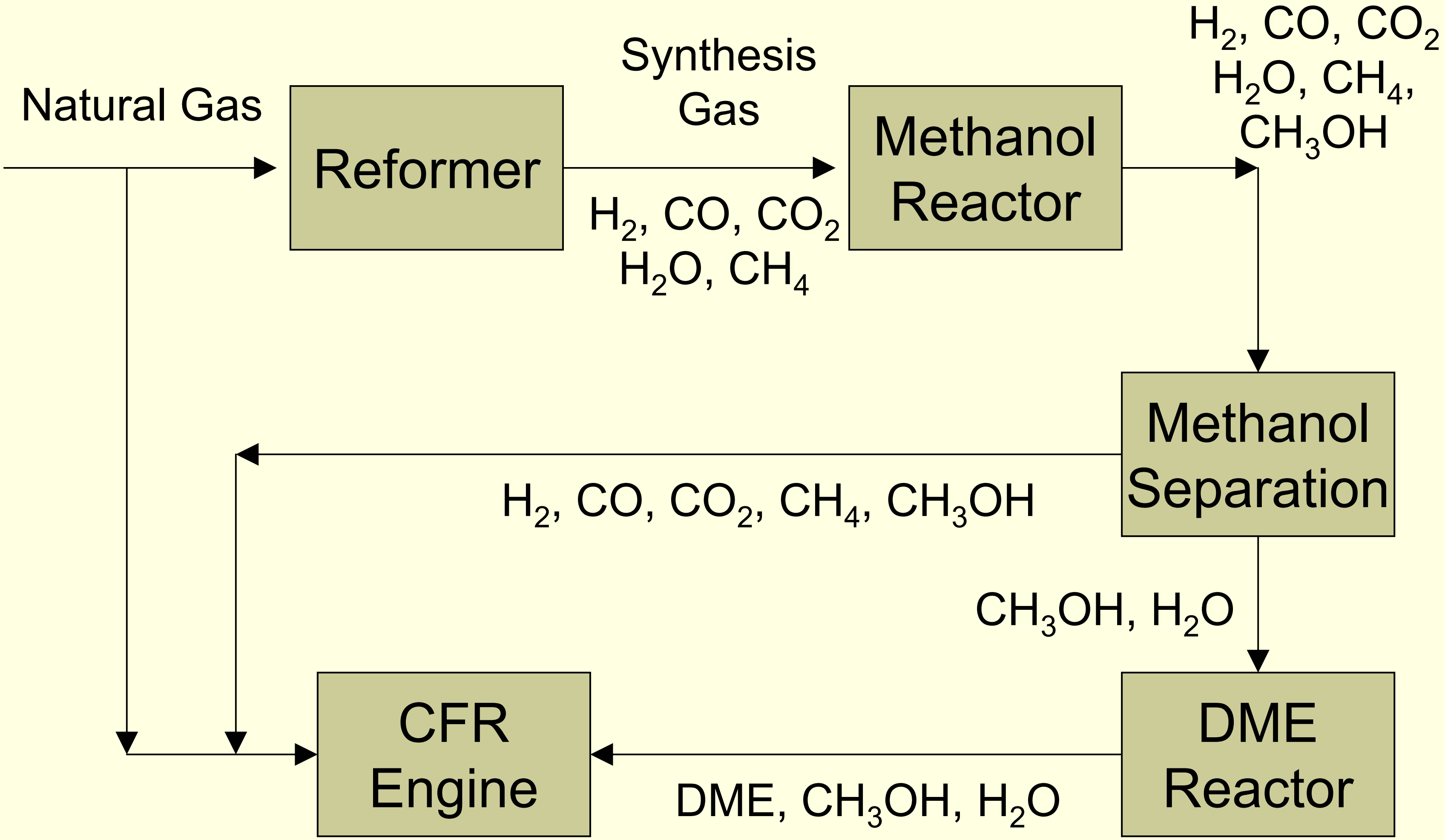
Project Background

- CFR engine modified to operate on natural gas (primary) with pilot injection DME
- DME production from natural gas desired in a one-pass process with gaseous byproducts fed with primary fuel
- DME solution achieved within range of good ignition characteristics (Sorenson, TUD)

Previous Work

- Construction of one-pass methanol-to-DME pilot plant by Dave Horstman, M.S. Thesis

Natural Gas to DME Schematic



Simulation Work

- ASPEN PLUS 11.1
- Steady-state equilibrium reaction model
- Soave-Redlich-Kwong EOS for reactor VLE
- Reformer simulation stand-alone (determined synthesis gas composition)
- Methanol and DME reactor simulations coupled assuming experimental setup
- Targeted DME solution mass flow rate: 0.24 kg/hr

DME from Natural Gas

Three-step process:

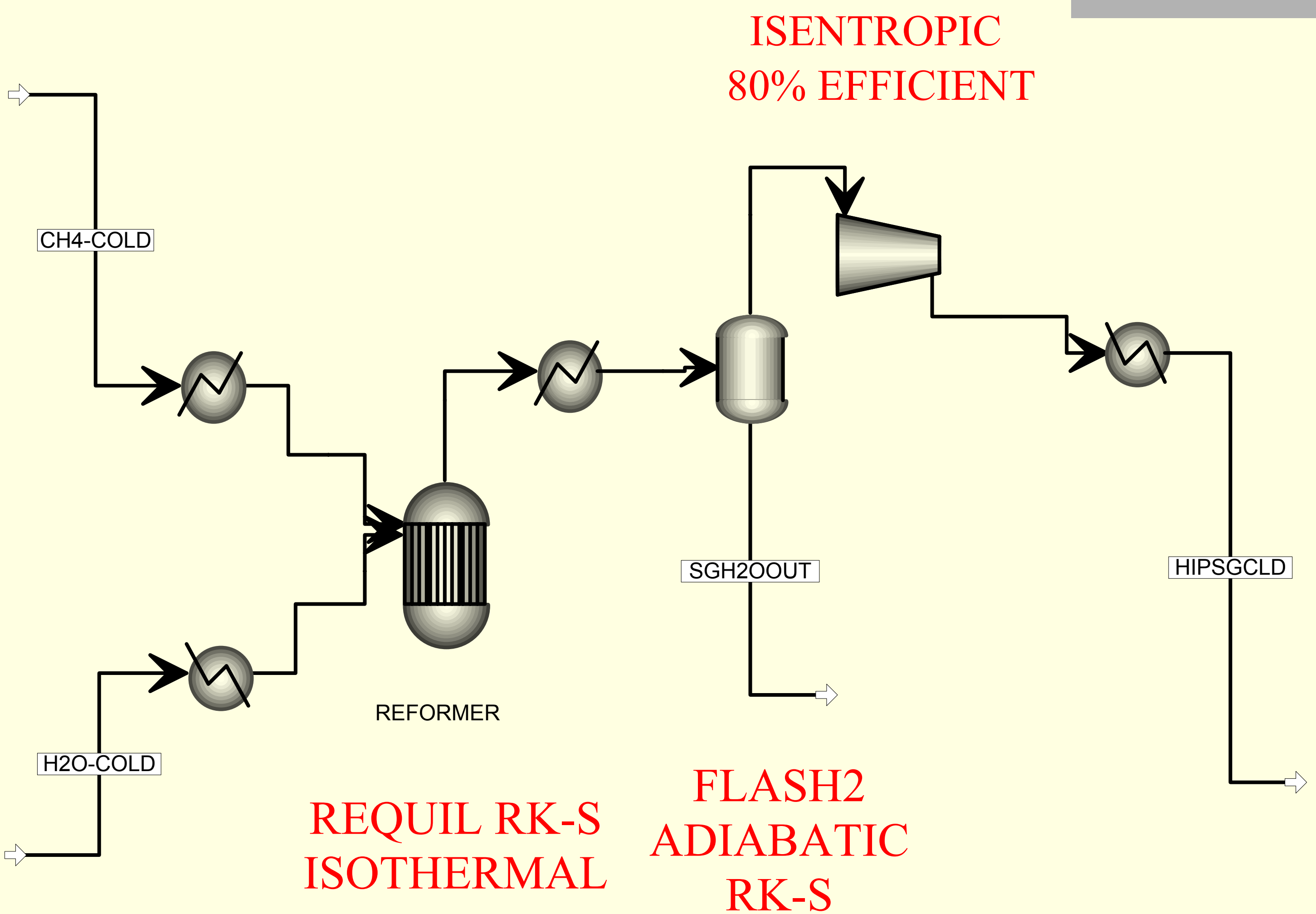
1. Synthesis gas (syngas) formation via reforming

- Steam, CO_2, Partial oxidation, autothermal
- Steam chosen for process simplicity

$$CH_4 + H_2O \Leftrightarrow CO + 3H_2$$
$$CO + H_2O \Leftrightarrow CO_2 + H_2$$

- Ni-based commercial catalyst
- Endothermic reaction, assumed gas-fired
- Simulated isothermal, 800-900°C, 1 – 5 bar
- Phase separation, residual water condensed; gas phase compressed, cooled, and sent to methanol reactor

Reformer Simulation



DME from Natural Gas

2. Methanol from synthesis gas

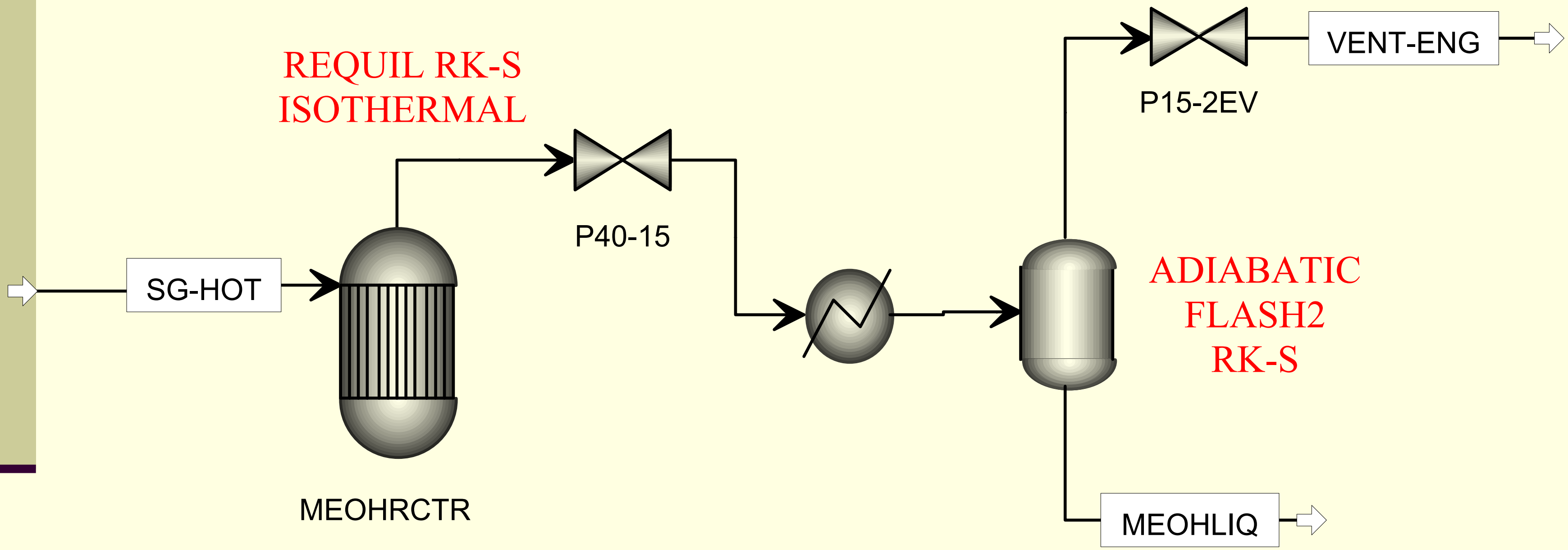
$$CO_2 + 3H_2 \Leftrightarrow CH_3OH + H_2O$$

$$CO + 2H_2 \Leftrightarrow CH_3OH$$

$$CO_2 + H_2 \Leftrightarrow CO + H_2O$$

- $CuO/ZnO/Al_2O_3$, commercial catalyst
- Simulated isothermal, 220-280°C, 20 – 40 bar
- Packed bed reactor, exothermic reaction
- Post-reaction phase separation at 15 bar
- Unreacted gas phase mixed with natural gas charge
- Liquid phase methanol solution fed to DME reactor

Methanol Simulation



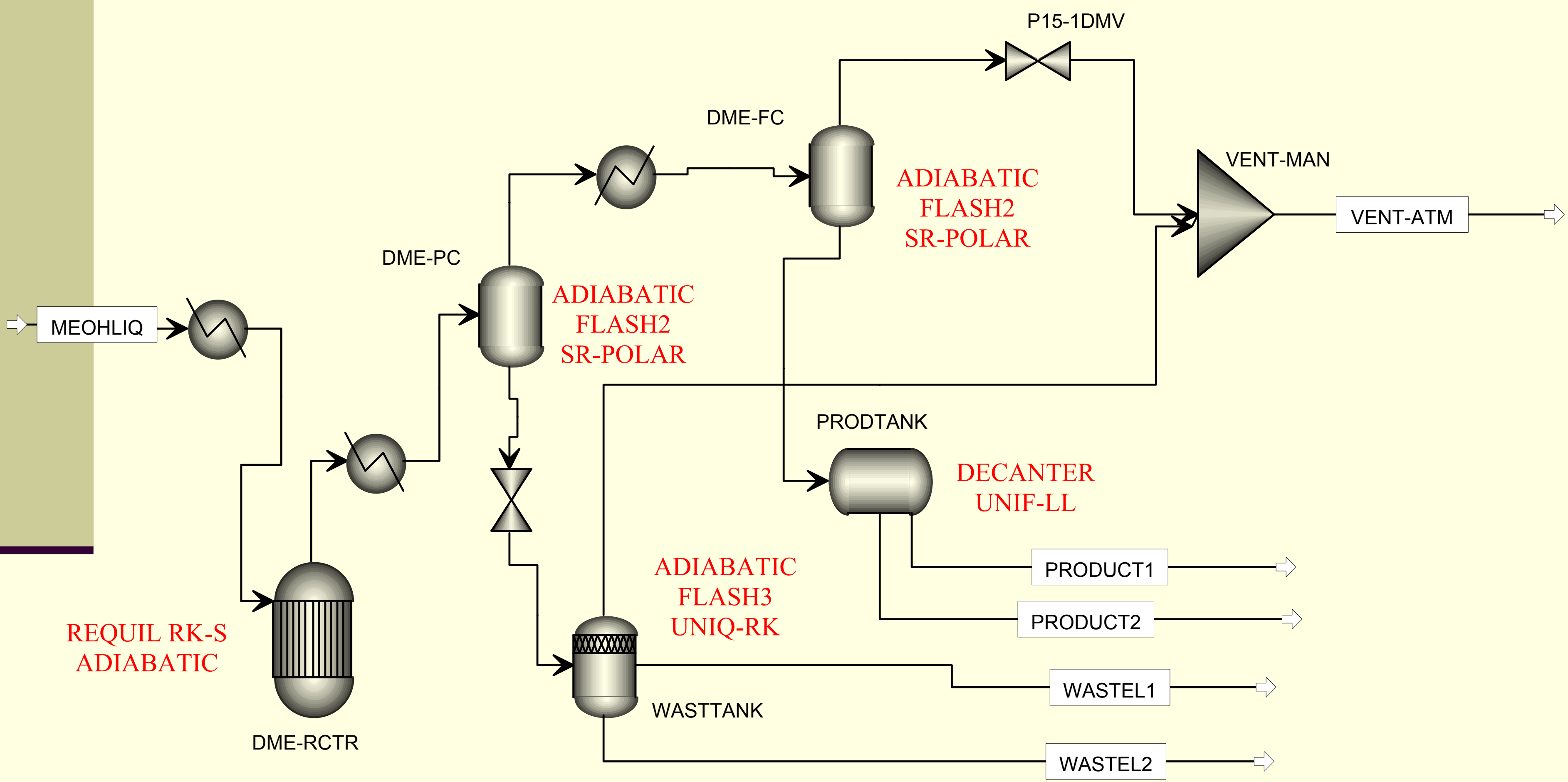
DME from Natural Gas

3. DME from methanol dehydration

$$2\,CH_3OH \Leftrightarrow H_3COCH_3 + H_2O$$

- γ-Al_2O_3 catalyst
- Simulated superheated methanol fed to adiabatic packed bed reactor at 300°C and 15 bar
- Partial condensation (waste)
- Full condensation (product)
- Product storage in propane LPG tank, 200 psi
- Horstman-constructed pilot unit at MTU, 2.5 kg/hr

DME Simulation



DME from Natural Gas

4. Alternate syngas to DME route, 1 reactor

$$CO_2 + 3H_2 \Leftrightarrow CH_3OH + H_2O$$

$$CO + 2H_2 \Leftrightarrow CH_3OH$$

$$CO_2 + H_2 \Leftrightarrow CO + H_2O$$

$$2CH_3OH \Leftrightarrow H_3COCH_3 + H_2O$$

- Mixed $CuO/ZnO/Al_2O_3$ and γ-Al_2O_3 catalyst
- Simulated isothermal reactor, 280°C, 40 bar
- Conversion good, effluent separation difficult
- Absorption potential, not pursued as viable option

Simulation Summary

- Simulated reformer syngas compositions established boundaries for experiment
- Methanol reactor simulations for 36 experiments predict offgas and product characteristics, 14 viable conditions (for DME production rate)
- DME simulations predict waste and product compositions, make rates, phase behavior
- Methanol and DME reactors to be compared to simulation experimentally

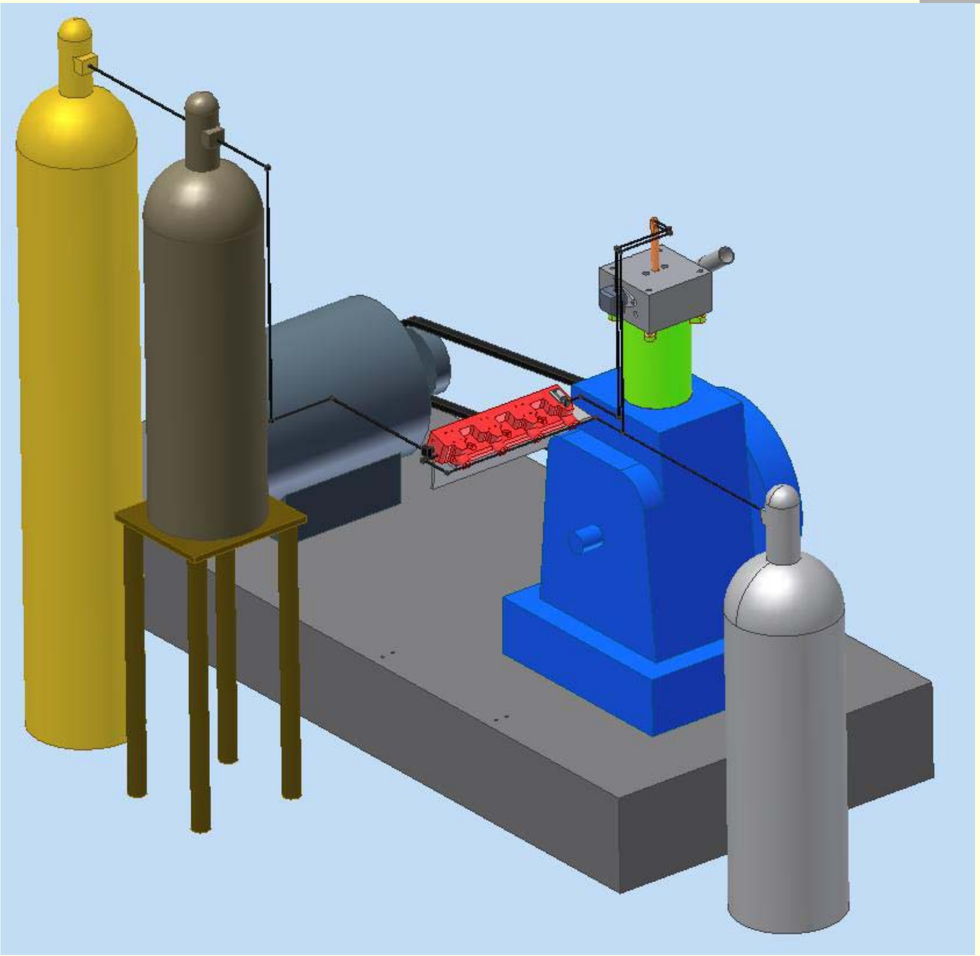
Present Work

- Isothermal reactor design at pilot rate for ~0.4 kg/hr methanol solution production
- Construction of experimental methanol reactor setup (stand-alone)
- Operation of existing DME pilot plant for further characterization of product and waste, and determination of true capacity
- CFR instrumentation and modification

CFR Parametric Combustion Study

- CFR adjustable head modifications complete
- Instrumentation in process
- Fuel rail modified
- Injector placed in modified CFR head
- Fuel system designed
- Pilot injection / combustion ignition operational target date 26 May 2003

Fuel System Challenges



- DME leakage rates are high (>360 g/min or 534 cc/min)
- Lubricity
- Delivery pressure / pumping methodology
- Charged and regulated pressure vessel is used as a pressure source for the common rail.
- Fuel feed pressure 3 to 3.5 Mpa
- Nozzle opening pressures 6.5 to 8.8 Mpa

Parametric Analysis

- Commencing 1 June 2003
- Explore DME pilot injections through a range of compression ratios
- Map development July through October 03
- Analyze emissions and ignition characteristics
- Analytical combustion model
- Examine extended operational range of HCCI with DME pilot injection

Technology Transfer

- SAE congress
- ASME ICE
- Individual meetings with ICAP stakeholders
- Publication of final results

Acknowledgments

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